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The Influence of Economic, Demographic, Technological, Environmental and Infrastructure Sectors on Indonesian Exports: The Role of Productivity as a Mediator

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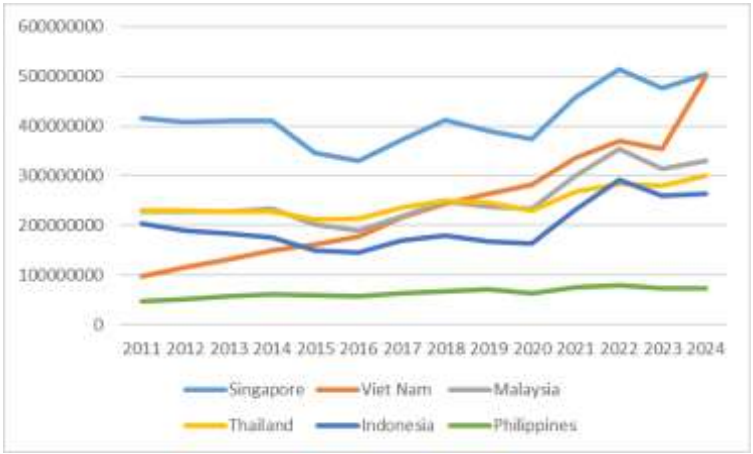
ABSTRACT: This research aims to analyze the influence of economic, demographic, technological, environmental, and infrastructure sectors on Indonesia's exports with total factor productivity (TFP) as the mediating variable. A quantitative approach was used with path analysis method, using secondary data from the period 1997–2022 obtained from BPS, World Bank, and IMF. The research results show that exchange rate, technological progress (number of scientific and technical articles), port efficiency (port output), and TFP have a positive and significant effect on Indonesia's exports. Meanwhile, labor force participation has no significant effect. Average annual temperature has a negative and significant effect, showing the adverse impact of climate change on natural resource-based export sectors. Bootstrap testing shows that TFP negatively mediates the effect of exchange rate on exports, indicating that exchange rate depreciation can reduce productivity efficiency in the long term. These findings emphasize the importance of balanced exchange rate policy as well as the strategic role of innovation, port infrastructure, and climate adaptation in driving national export performance.

I. INTRODUCTION

International trade can affect a country's economy, particularly in aspects of consumption, production, and income distribution (Sjahril, 2013). Many previous studies have shown the positive impact of international trade on a country's economic growth. According to Laorens (2023), international trade can provide various positive impacts for a country's economy, such as encouraging innovation, expanding markets, and increasing productivity, all of which contribute to economic progress. It also provides a wide variety of goods and services through trade at affordable prices for domestic consumers, and facilitates the transfer of technology, expertise, and innovation between countries. The positive impact provided by international trade has made countries around the world increasingly active in enhancing their international trade activities. This is evidenced by the increasing value of trade among countries worldwide from year to year, including Indonesia.

Figure 1: Total Exports of ASEAN Countries



Based on export data from ASEAN countries for the period 2011-2022, it can be seen that Indonesia's export performance lags behind that of Singapore, Malaysia, and even Vietnam. Countries like Vietnam experienced a significant surge in exports, increasing by 283% from 2011-2022. Meanwhile, Indonesia's export trend tends to be volatile and shows no significant growth, with only 43% growth compared to Malaysia's 56%. A country with abundant resources like Indonesia should be able to achieve even higher export growth.

In practice, international trade is a complex activity consisting of various stages that involve multiple other fields. These fields can include economics, demographics, technology, environment, infrastructure, and others. One factor that can influence international trade activity is productivity. There is a hypothesis stating that companies with high productivity tend to engage in exports. This hypothesis is called the Self-Selection Hypothesis. Economically, there are many factors that can affect international trade, and one of them is the exchange rate. The impact of exchange rates on international trade can be said to be ambiguous because the impact can be positive or negative and depends greatly on transaction requirements and the behavior of trading countries (Mehtiyev, J., Magda, R., & Vasa, L., 2021).

Furthermore, the demographic field also contains factors that can influence international trade. The WTO (2008) states that demographic changes affect trade through their impact on a country's comparative advantage and import demand. One demographic factor that can affect exports is labor force participation. Basically, labor is one of the production factors that can affect the total output of exported goods. However, economic theory contains a basic assumption regarding the nature of the production function: that all producers are considered to follow the Law of Diminishing Marginal Returns. According to Arif and Amalia (2010), this law states that when one type of input is increased while other inputs remain constant, the additional output generated will initially increase. However, after passing a certain point, the additional output will decrease as the input continues to increase.

Furthermore, there is the technology sector that can also influence international trade activities. Barus (2024) states that technology enables companies to explore and exploit global market opportunities more efficiently through instant communication and broad access to information. Greenlaw and Shapiro (2011) mention that technology, in its economic sense, refers broadly to all new production methods, which include major scientific discoveries as well as minor innovations and even improved forms of management or other types of institutional arrangements.

The environment sector can also affect international trade through several factors, such as average temperature. Martinez (2023) mentions that rising temperatures are considered one of the main drivers of the high prevalence of extreme weather events such as tornadoes, storms, floods, and other directly related adverse impacts such as forest fires, sea level rise, insect attacks, or epidemics. This phenomenon can affect international trade through three different pathways: infrastructure damage, declining labor productivity, and the opening of new routes.

Another field that can affect international trade activity is infrastructure. Han (2022) mentions that it is generally believed that better infrastructure can reduce the costs of both international and domestic trade, where international trade refers to trade flows that cross national borders while domestic trade is defined as the opposite, regardless of whether these trade flows are inter-industry or not. The sea is one of the main routes used by importers and exporters to transport traded goods. Therefore, it is important to have highly efficient ports to ensure productivity and security in international trade processes.

To improve Indonesia's export performance in the international market, it is important to identify the factors that influence it. Many previous studies have investigated the factors affecting Indonesian exports, but few studies have used factors from various sectors such as economics, demographics, technology, environment, and infrastructure to achieve more holistic research results. Therefore, this study aims to fill this research gap. This study also uses productivity as a mediator variable to determine whether a country's productivity can mediate the studied factors' effects on Indonesian exports.

II. LITERATURE REVIEW

A. International Trade

International trade refers to the activity of buying and selling goods, services, and capital across national borders. According to McConnell (2001), this trade can occur both physically and electronically. Rusydiana (2009) emphasizes that this activity involves exports and imports between countries to achieve maximum profit, while Wibowo (2024) adds that it can occur at various scales and between individuals, governments, or a combination thereof.

The concept of comparative advantage, introduced by David Ricardo (1817), is a cornerstone of modern international trade theory. Ricardo argued that trade is driven not by absolute productivity differences, but by relative ones. A country can remain competitive in exporting a good, even if another nation is more efficient in producing everything, as long as its opportunity cost for that specific good is lower. Thus, with low trade costs, nations can benefit from specialization and trade based on their relative productivity.

The Heckscher-Ohlin model offers a structural approach, emphasizing differences in the relative endowment of production factors like land, labor, and capital. Countries tend to export goods that intensively use their abundant factors and import goods that

require scarce factors. In this view, international trade is an indirect form of factor arbitrage, transferring factor services from where they are abundant to where they are scarce. This integrates global input markets, making demand for factors of production more elastic and similar across countries.

B. Productivity

Theoretically, productivity is the amount of output (goods or services) generated per unit of input used in the production process (Syverson, 2011). It serves as a key indicator of efficiency. A widely used measure is Total Factor Productivity (TFP), which, according to Durlauf and Blume (2010), represents the portion of output not explained by the accumulation of inputs, reflecting technological progress and managerial efficiency. TFP is crucial for long-term economic growth and explaining income differences between countries (Solow, 1956).

In the context of international trade, TFP plays a vital role. The "self-selection" hypothesis posits that only highly productive firms can bear the sunk costs of entering export markets (Roberts & Tybout, 1997). Conversely, the "learning by exporting" view suggests that exporting itself drives firms to become more productive through global competition and knowledge transfer (Grossman & Helpman, 1991). Empirical work by Cai and Wang (2020) supports this, finding a significant positive correlation between agricultural TFP and agricultural exports in Hunan Province, confirming that efficiency gains boost global competitiveness.

C. Exchange Rate

The exchange rate is the price of one country's currency in terms of another (Pilbeam, 2023). Its fluctuations significantly impact a nation's international competitiveness. Porter (1990) noted that while currency depreciation can negatively pressure growth, it can sometimes boost productivity in the tradable goods sector. This aligns with Harris (2010), who links the exchange rate and productivity through international competitiveness, as currency fluctuations alter the relative prices of products on the global market.

Sukirno (2013) highlights that under a floating exchange rate system, depreciation enhances export competitiveness by making domestic products relatively cheaper for foreign buyers. Ginting (2013) adds that in a small open economy, exchange rates are influenced by global interest rate dynamics. An increase in the domestic money supply can lower interest rates, prompting capital outflow and causing currency depreciation. This, in turn, makes domestic goods more competitive, boosting exports.

D. Labor

Labor is defined as any individual capable of performing work to produce goods or services (Law No. 13/2003; Djojohadikusumo, 1994). It is a primary component of a country's workforce, which includes all individuals of working age who are employed or actively seeking employment (BPS). International trade, particularly exports, is fundamentally linked to production. This relationship is often captured by the production function:

$$Q=f(K,L,R,T)$$

where output (Q) is a function of capital (K), labor (L), natural resources (R), and technology (T) (Zahara, 2020). Labor, as a key input, directly influences the volume and efficiency of production, thereby affecting a nation's export capacity. Furthermore, human capital (the quality of labor) drives TFP growth by facilitating technology adoption and domestic innovation (Nelson & Phelps, 1966; Romer, 1990; Aghion & Howitt, 1998). However, economic theory also recognizes the Law of Diminishing Returns, which states that continuously increasing one input while holding others constant will eventually lead to smaller increases in output (Arif & Amalia, 2010). Therefore, enhancing labor productivity must be complemented by advancements in other inputs like technology and capital to ensure optimal output growth.

E. Technological Progress

Grossman and Helpman (1989) argue that comparative advantage is dynamic and must be cultivated through investment in research and development (R&D). Technological innovation is a primary driver of long-term economic growth. In international trade, technology serves as a critical intangible resource for competitive advantage (Rodriguez, 2005).

According to the resource-based view (Barney, 1991), resources that are valuable, rare, inimitable, and non-substitutable (VRIN) can create a sustainable competitive advantage. Technology fits these criteria, making it a strategic asset for international expansion. It provides a competitive edge through two main channels: cost efficiency, by improving production processes, and product differentiation, through innovations that create higher-quality or better-tailored products. Studies confirm that innovation-driven product differentiation is a key determinant of export success. Fauzel (2022), for instance, found that technological progress had a significant positive impact on trade for a sample of COMESA countries. This indicates that technology investment enhances both internal efficiency and international competitiveness.

F. Climate Change

Climate change refers to long-term shifts in global or regional weather patterns, evidenced by changes in temperature, precipitation, and sea levels (UN-Habitat). It is largely driven by human activities that produce greenhouse gas emissions (Hermon, 2017). Climate change has direct implications for economic activities, including international trade, with some research indicating complex and sector-specific impacts (Martinez, 2023). Climate change poses significant challenges to global trade. The WTO (2009) notes that extreme weather can disrupt global supply chains, logistics, and distribution. These disruptions can cause shipping delays and increase transportation costs. Martinez (2023) identifies three main channels of impact: 1) physical disruptions from extreme weather events, 2) negative effects on labor productivity and biological risks, and 3) the potential opening of new sea routes due to melting polar ice, which presents both opportunities and new geopolitical challenges.

G. Port Efficiency

The process of shipping and transporting goods is as critical to international trade as tariffs or exchange rates. A reduction in transport costs is a major driver of global trade growth (Hummels, 2007). Given that approximately 80% of global trade volume is transported by sea (UNCTAD, 2014), the efficiency of seaports is paramount for regional economic competitiveness (Merk, 2012).

Pallis and Rodrigue (2022) define port efficiency as a multidimensional concept focused on maximizing output with limited resources by optimizing operational performance. Key performance indicators include production, productivity, utilization, and service quality. Efficient ports reduce logistical costs and accelerate the flow of goods. Research by Mlambo & Courage (2021) confirms that port performance has a significant positive impact on international trade in Africa, suggesting that improving port efficiency is a key factor in strengthening productivity and global integration.

Based on prior theoretical and empirical studies, these are the hypotheses that are used in this study:

H1a: Exchange rate depreciation has a positive effect on Productivity.
H1b: Exchange rate depreciation has a positive effect on Indonesian exports.
H1c: Productivity mediates the relationship between the exchange rate and Indonesian exports.
H2a: Labor Participation Rate has a positive effect on Productivity.
H2b: Labor Participation Rate has a positive effect on Indonesian exports.
H2c: Productivity mediates the relationship between Labor Participation Rate and Indonesian exports.
H3a: Scientific and Technical Journal Article has a positive effect on Productivity.
H3b: Scientific and Technical Journal Article has a positive effect on Indonesian exports.
H3c: Productivity mediates the relationship between Scientific and Technical Journal Article and Indonesian exports.
H4a: Annual Average Temperature has a negative effect on Productivity.
H4b: Annual Average Temperature has a negative effect on Indonesian exports.
H4c: Productivity mediates the relationship between Annual Average Temperature and Indonesian exports.
H5a: Port Output has a positive effect on Productivity.
H5b: Port Output has a positive effect on Indonesian exports.
H5c: Productivity mediates the relationship between Port Output and Indonesian exports.

III. METHODOLOGY

This research uses a quantitative approach with path analysis method to test direct and indirect relationships between variables. Path analysis was chosen because it can identify the mediating role of productivity in influencing Indonesian exports. The data used in this study is secondary data spanning 26 years, from 1997 to 2022. The data sources used in this research were obtained from publications issued by the Central Bureau of Statistics (BPS), World Bank Data, and the International Monetary Fund (IMF). The data used includes currency exchange, labor participation rate, scientific and technical journal articles, annual average temperature, port output, total factor productivity, and Indonesian exports (Y). To calculate the indirect effects of independent variables, the Bootstrap test was used. Bootstrapping is a computationally intensive method that involves multiple processes of resampling data and estimating indirect effects in each resampled dataset. The regression equation used is as follows:

Equation I: $Z = \alpha + \beta1X1 + \beta2X2 + \beta3X3 + \beta4X4 + \beta5X5 + e1$

Equation II: $Y = \alpha + \beta1X1 + \beta2X2 + \beta3X3 + \beta4X4 + \beta5X5 + \beta6Z + e2$

Information:

Z = Total Factor Productivity (TFP)
Y = Export volume
X1 = Rupiah to USD exchange rate
X2 = Labor force participation rate
X3 = Number of scientific and technical journal articles

X4 = Average annual temperature
X5 = Port container traffic (port output)
$\rho_p$yxi = Path coefficient from Xi to Y
$\rho_p$zxi = Path coefficient from Xi to Z
e1 = Error term affecting Z
e2 = Error term affecting Y

IV. RESULTS AND DISCUSSIONS

A. Descriptive Statistics

Table 1 Descriptive Statistics

	N	Min	Max	Mean	Std. Deviation
X1	26	2,909.38	14,849.85	10,621	2,766.19
X2	26	66.42	70.57	68.72	0.97
X3	26	317.04	39,566.05	7,689.28	12,386.67
X4	26	25.73	26.24	26.00	0.13
X5	26	180,838	600,211	335,591	139,652.13
Z	26	0.880	1.150	0.971	0.048
Y	26	1.75e+13	4.80e+13	1.75e+13	1.16e+13
N	26				

Source: Author's computation using SPSS 26 (2025)

Descriptive statistical analysis was conducted on all variables using a balanced dataset of 26 observations per variable. The currency exchange rate showed a substantial range, with values spanning from IDR 2,909.38 to IDR 14,849.85. The mean exchange rate was IDR 10,621.51, with a standard deviation of IDR 2,766.19, indicating a notable degree of fluctuation over the observed period. The labor force participation rate ranged from 66.42% to 70.57%, with a relatively stable mean of 68.73% and a low standard deviation of 0.97, suggesting minor variations annually. The number of scientific and technical journal articles demonstrated the highest level of dispersion among all variables, ranging from 317.04 to 39,566.05 articles. The mean was 7,689.28 with a standard deviation of 12,386.68, indicating a right-skewed distribution and significant growth in scientific output over time.

Annual average temperature exhibited the least variation, with values ranging narrowly between 25.73°C and 26.24°C. The mean temperature stood at 26.00°C, accompanied by a standard deviation of just 0.13°C, reflecting Indonesia's stable tropical climate. Port output, representing logistical activity, ranged from 180,838 to 600,211 units, with a mean of 335,591.50 and a standard deviation of 139,652.13, highlighting moderate variability in port performance. Total Factor Productivity (TFP) values ranged from 0.88 to 1.16, with an average of 0.97 and a standard deviation of 0.048, indicating relatively stable productivity efficiency across the years. Lastly, total Indonesian exports demonstrated the widest value distribution, ranging from IDR 17.49 trillion to IDR 47,998.15 trillion. The average export value was IDR 17,523.55 trillion, with a standard deviation of IDR 11,629.68 trillion, emphasizing significant fluctuations in trade performance over the observed period.

B. Normality Test

Table 2 Normality Test Result

	Model 1	Model 2
Tes Statistic	.119	.156
Asymp. Sig. (2-tailed)	.200[c,d]	.102[c]

Source: Author's computation using SPSS 26 (2025)

Based on the results of the normality test for both models as shown in the table, the Asymp. Sig value are greater than the significance level of 0.05. This indicates that Model 1 and Model 2 satisfies the normality assumption, meaning the data in the model is normally distributed.

C. Multicollinearity Test

Table 3 Multicollinearity Test Result

	Model 1		**Model 2**	
	Tolerance	**VIF**	**Tolerance**	**VIF**
X1	.330	3.032	.173	5.774
X2	.679	1.472	.673	1.485
X3	.407	2.454	.403	2.484

X4	.667	1.499	.659	1.519
X5	.495	2.021	.438	2.281
Z			.387	2.587

Source: Author's computation using SPSS 26 (2025)

Based on the results of the multicollinearity test presented in the table, all independent variables show VIF values less than 10 and tolerance values greater than 0.1. This indicates that there is no excessively high correlation among the independent variables, and thus, the research model can be considered free from multicollinearity issues.

D. Heteroscedasticity Test

Table 4 Heteroscedasticity Test Result

	Model 1		**Model 2**	
	t	**Sig**	**t**	**Sig**
X1	-1.855	.078	.176	.862
X2	1.765	.093	.189	.852
X3	1.698	.105	1.029	.316
X4	-.570	.575	-.184	.856
X5	-1.116	.278	.431	.671
Z			.258	.799

Source: Author's computation using SPSS 26 (2025)

The results of the heteroskedasticity test indicate that the significance values for all independent variables are greater than the 0.05 significance level. According to the Glejser test criteria, this condition suggests that the homoskedasticity assumption is fulfilled. Therefore, the data in this model is free from heteroskedasticity issues.

E. Autocorrelation Test

Table 5 Autocorrelation Run Test Result

	Model 1	Model 2
Asymp. Sig. (2-tailed)	.072	.548

Source: Author's computation using SPSS 26 (2025)

The results of the autocorrelation test in the table above show a significance value of 0.072 and 0.548 which is greater than the alpha level of 0.05. This indicates that the data is free from autocorrelation.

F. Multiple Linear Regression Analysis – Model 1

Based on the results of the analysis using SPSS, the regression output shows the relationship between the independent variables currency exchange (X1), labor participation rate (X2), scientific and technical journal articles (X3), annual average temperature (X4), and port output (X5) and the dependent variable Total Factor Productivity (TFP) (Z). The detailed regression results are presented as follows:

Table 6 Multiple Linear Regression Analysis – Model 1 Result

Variabel	**B**	**t**	**Sig**
Constant	0.550	0.339	0.738
X1	-1.029	-4.253	0.000
X2	-0.071	-0.422	0.677
X3	0.108	0.497	0.625
X4	0.086	0.504	0.619
X5	0.317	1.605	0.124
R Square	0.613		
F-statistic	6.349		

Source: Author's computation using SPSS 26 (2025)

G. Multiple Linear Regression Analysis – Model 2

Based on the results of the analysis using SPSS, the regression output shows the relationship between the independent variables currency exchange (X1), labor participation rate (X2), scientific and technical journal articles (X3), annual average temperature

(X4), port output (X5), and Total Factor Productivity (TFP) (Z) and the dependent variable Indonesia's exports (Y). The regression results are presented as follows:

Table 7 Multiple Linear Regression Analysis – Model 2 Result

Variabel	B	t	Sig
Constant	38,333,974,131,147,160	2.713	0.014
X1	0.696	5.797	0.000
X2	-0.023	-0.380	0.708
X3	0.262	3.323	0.004
X4	-0.201	-3.260	0.004
X5	0.439	5.815	0.000
Z	0.290	3.603	0.002
R Square	0.952		
F Hitung	63.534		

Source: Author's computation using SPSS 26 (2025)

H. Bootstrap Test

Based on the results of the analysis using SPSS, the regression output shows the relationship between the independent variables currency exchange (X1), labor participation rate (X2), scientific and technical journal articles (X3), annual average temperature (X4), port output (X5), and Total Factor Productivity (TFP) (Z) and the dependent variable Indonesia's exports (Y). The regression results are presented as follows:

Table 8 Bootstrap Test Result

Variabel	Effect	BootLLCI	BootULCI
X1	-0.3467	-0.7207	-0.0500
X2	.0714	-.0232	.1723
X3	.0005	-.4526	.1437
X4	0.0932	-.0638	0.2736
X5	0.0504	-0 .0274	0.1388

Source: Author's computation using SPSS 26 (2025)

I. DISCUSSION

The regression results of Model 1 reveal an R-squared value of 0.613, indicating that approximately 61.3% of the variation in Total Factor Productivity (TFP) in Indonesia can be explained by five independent variables: exchange rate, labor force participation rate, scientific and technical journal publications, annual average temperature, and port efficiency. This suggests the model has a relatively strong explanatory power in capturing the dynamics of TFP within the Indonesian context.

Individually, the exchange rate variable shows a statistically significant negative effect on TFP (β = -1.029; Sig. = 0.000). This finding supports Porter's (1990) argument that excessive currency depreciation can hamper economic growth, and is consistent with Diallo (2015), who found that real exchange rate appreciation in developing countries tends to reduce efficiency and depress total productivity. For Indonesia, exchange rate volatility often increases the cost of imported inputs, especially in import-intensive manufacturing sectors, thus lowering production efficiency and overall TFP. In contrast, the labor force participation rate does not exhibit a significant effect on TFP (β = -0.071; Sig. = 0.677). This result suggests that a quantitative increase in labor supply alone is insufficient to drive productivity growth without parallel improvements in human capital. The finding aligns with Setiyawati (2020) and the theoretical framework of Nelson & Phelps (1966), which highlight the role of human capital in facilitating technological adoption. In line with the law of diminishing returns, labor increases without innovation or technology upgrades yield limited marginal gains to national output. Technological advancement, proxied by the number of scientific and technical publications, also lacks a significant impact on TFP (β = 0.108; Sig. = 0.625). This diverges from findings by Chou et al. (2014), who emphasize the importance of R&D in driving productivity. The divergence may stem from limitations in the indicator's ability to capture the effectiveness of research implementation within the industrial sector. A persistent gap between academia and real-world application continues to hinder the aggregate effect of ICT capital deepening on productivity. Similarly, annual average temperature does not significantly affect TFP (β = 0.086; Sig. = 0.619). This contradicts Kumar & Maiti (2023), who found that temperature increases tend to lower productivity in developing economies. The lack of a significant effect in Indonesia could be attributed to minimal temperature variation during the observation period or the country's high climate adaptability. As a tropical nation, Indonesia appears relatively resilient to small temperature fluctuations, limiting their impact on production efficiency. Finally, port efficiency—measured through port output—shows a positive but statistically insignificant

relationship with TFP (β = 0.317; Sig. = 0.124). Although the coefficient's direction aligns with literature (Munim & Schramm, 2018; Merk, 2012), which underscores the productivity benefits of efficient port infrastructure, the results suggest that improvements in port throughput have not been accompanied by equivalent gains in service quality, logistics digitalization, or turnaround efficiency. Regional infrastructure disparities may also obscure the overall national impact of port development on productivity.

Model 2 yields an R-squared value of 0.952, suggesting that 95.2% of the variation in total Indonesian exports can be explained by six key variables: exchange rate, labor force participation, number of scientific and technical journal publications, annual average temperature, port efficiency, and TFP. This demonstrates the model's strong explanatory power in identifying the main drivers of Indonesia's export performance. Individually, the exchange rate exerts a significant positive influence on exports (β = 0.696; Sig. = 0.000). A depreciated rupiah enhances the price competitiveness of Indonesian goods in international markets, consistent with the Marshall-Lerner condition and supported by Ginting (2013), who emphasized the role of exchange rates in boosting commodity-based exports, such as coal and palm oil. Conversely, labor force participation does not show a statistically significant effect (β = -0.023; Sig. = 0.708), reinforcing earlier findings that quantitative labor increases do not necessarily translate into export growth without improvements in labor quality (Lestari, 2016). Technological advancement, as reflected by the number of scientific publications, displays a significant positive effect on exports (β = 0.262; Sig. = 0.004). This supports the endogenous growth theory (Grossman & Helpman, 1991), which posits that innovation drives comparative advantage. Research and technology enable product differentiation and enhance efficiency, both of which are critical for strengthening export competitiveness. On the other hand, annual average temperature exerts a negative and significant influence on exports (β = -0.201; Sig. = 0.004). This aligns with WTO (2009) and Kumar & Maiti (2023), who argue that climate change disrupts production and supply chains—particularly in natural resource-based export sectors such as agriculture and fisheries. Port efficiency is also found to have a strong positive and significant effect on exports (β = 0.439; Sig. = 0.000). Higher port output reflects improved logistics services and throughput, which reduce export costs and enhance delivery speed. This finding is consistent with the arguments of Hummels (2007) and Merk (2012), who emphasize the strategic role of port infrastructure in global trade—especially for archipelagic countries like Indonesia. Finally, TFP contributes significantly and positively to export performance (β = 0.290; Sig. = 0.002). This supports the self-selection theory (Roberts & Tybout, 1997), which suggests that only highly efficient firms are able to compete globally. Thus, improving TFP is crucial for sustaining Indonesia's long-term export competitiveness.

The bootstrapping analysis of TFP's mediating role in the relationship between the independent variables and exports reveals that most indirect paths are statistically insignificant. Bootstrap confidence intervals for labor force participation, technological advancement, temperature, and port efficiency include zero, indicating that TFP does not significantly mediate their effect on exports. However, a significant indirect effect is observed for the exchange rate variable. The exchange rate has a statistically significant indirect negative effect on exports via TFP, with an effect size of -0.3467 and a bootstrap confidence interval of (-0.7207, -0.0500), which does not include zero. This implies that while exchange rate depreciation directly boosts exports, it may simultaneously reduce TFP, creating an offsetting negative impact. This dual effect may be explained through several mechanisms. First, currency depreciation raises the cost of imported raw materials and capital goods, particularly those related to technology-intensive production, thereby lowering input efficiency and TFP. This aligns with the definition of TFP as output not explained by labor and capital inputs (Durlauf & Blume, 2010). Second, this finding supports the price competitiveness theory (Porter, 1990; Harris, 2010), suggesting that gains from currency depreciation may be eroded by productivity losses due to dependence on imported inputs. Third, it reinforces Diallo's (2015) view that real exchange rate misalignment can negatively impact TFP growth in developing economies reliant on external inputs and lacking fully efficient economic structures.

V. CONCLUSIONS

This study examines the impact of exchange rate, labor force participation, technological advancement, average temperature, and port efficiency on Indonesia's exports, while also assessing the mediating role of Total Factor Productivity (TFP). Several key findings emerge from the analysis. First, the exchange rate is found to have a significant positive effect on Indonesian exports. A depreciated rupiah enhances the price competitiveness of domestic products in global markets, consistent with the Marshall-Lerner condition. However, mediation analysis reveals an important caveat: while depreciation directly supports export growth, it also exerts a significant negative indirect effect through a decline in TFP. This suggests that in the long run, depreciation may hinder production efficiency due to higher costs of imported inputs, particularly in import-dependent industries. Second, labor force participation—measured in quantitative terms—does not have a statistically significant impact on exports. This underscores the importance of enhancing human capital quality rather than merely expanding labor quantity. In contrast, technological advancement, proxied by the number of scientific publications, shows a significant positive effect on exports. This reinforces the role of research and innovation in building product competitiveness, in line with endogenous growth theory. Third, annual average temperature—used as a proxy for climate change—has a significant negative impact on export performance. This finding reflects the vulnerability of Indonesia's export sectors, particularly natural resource-based industries such as agriculture and fisheries, to

climatic disruptions. Meanwhile, port efficiency demonstrates a significant positive contribution to exports, confirming that logistics infrastructure plays a critical role in facilitating trade flows. Last, TFP itself is shown to have a significant positive effect on export performance, highlighting the central role of aggregate production efficiency in enhancing national export competitiveness. Together, these findings emphasize that sustainable export growth requires not only favorable external conditions, such as exchange rates and logistics, but also structural improvements in productivity, innovation, and climate resilience.

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